THE COMPOSITION OF A DESERT LICHEN FLORA*

Bruce Fink

The plants upon which the considerations to follow are based were collected in the vicinity of the Carnegie Botanical Laboratory. The collections and field notes were made by Messrs. J. C. Blumer and V. M. Spalding. The collecting was quite carefully done, and a considerably larger amount of material was examined than the rather short list of species given below would indicate. That the list falls considerably short of the entire lichen flora of the area is indicated by the fact that each collection, after the first, brought to light one or more new forms, though collected at random and including a small number of species. However, lichens collected by persons not well acquainted with lichen species are likely to be the more common, conspicuous and characteristic ones. Therefore, some valuable conclusions can be drawn from the study of these specimens, together with a statement of problems which could be solved only through an exhaustive study on the ground, by one well acquained with lichens and the problems and methods of work in ecology. The list of species is as follows:

1. *Endocarpiscum placodizans* (A. Zahlbr.) Fink.
2. *Heppia deserticola* A. Zahlbr. Bull. Torr. Bot. Club **35**: 300. 1908.
3. *Heppia virescens* (Despr.) Nyl. Syn. Lich. **2**: 45. 1860.
4. *Pyrenopsis Schaereri* (Mass.) Tuck. Syn. North Am. Lich. **1**: 135. 1882.
5. *Collema* sp., sterile.
6. *Synechoblastus coccophorus* (Tuck.) Fink.
7. *Leptogium arizonicum* A. Zahlbr. Bull. Torr. Bot. Club **35**: 299. 1908.

* Contributions from the Botanical Laboratory of Miami University—II.

8. *Acarospora xanthophana* (Nyl.) Fink, Bot. Gaz. **38**: 271. 1904.
9. *Acarospora xanthophana dealbata* (Tuck.) Fink.
10. *Acarospora Carnegiei* A. Zahlbr. Bull. Torr. Bot. Club **35**: 297. 1908.
11. *Acarospora cervina cinereoalba* Fink, Minn. Bot. Stud. **2**: 319. 1899.
12. *Acarospora cineracea* (Nyl.) Hedlund in Litt.
13. *Lecanora muralis* (Schreb.) Tuck. Gen. Lich. 113. 1872.
14. *Lecanora cinerea* (L.) Sommerf. Suppl. Fl. Lapp. 99. 1826.
15. *Lecanora calcerea contorta* (Hoffm.) Tuck. Syn. North Am. Lich. **1**: 199. 1882.
16. *Placodium elegans* (Link.) Ach. Lich. Suec. Prod. 102. 1798.
17. *Placodium elegans brachylobum* (A. Zahlbr.) Fink.
18. *Placodium murorum* (Hoffm.) Ach. Lich. Suec. Prod. 101. 1798.
19. *Placodium cinnabarinum* (Ach.) Anzi, Lich. Sondr. **1**: 43. 1860.
20. *Placodium amabile* (A. Zahlbr.) Fink.
21. *Placodium lobulatum* (Sommerf.) Fink.
22. *Teloschistes modestus* (A. Zahlbr.) Fink.
23. *Parmelia conspersa* (Ehrh.) Ach. Meth. Lich. 205. 1803.
24. *Physcia* sp.
25. *Buellia lepidastra* Tuck. Syn. North Am. Lich. **2**: 90. 1888.
26. *Buellia* sp., near *B. concinna* Th. Fr. Lich. Arct. 232. 1860. (fide Theodor Hedlund).
27. *Dermatocarpon miniatum* (L.) Fr. Syst. Orb. Veg. 259. 1825.
28. *Dermatocarpon peltatum* (Tayl.) Fink.
29. *Dermatocarpon* sp., near *D. compactum* (Mass.) Fink.
30. *Dermatocarpon rufescens* (Ach.) A. Zahlbr. in Eng. and Pr. Pflanzenfam. **1**^{7}: 60. 1907.
31. *Endocarpon Schaereri* (Koerb.) Fink.
32. *Verrucaria fuscella* (Turn.) Ach. Lich. Univ. 289. 1810.
33. *Verrucaria nigrescens* Pers. Ust. Ann. Bot. **14**: 36. 1795.

These lichens form a remarkable assemblage of plants. The collectors were asked to find any loosely foliose or fruticose lichens, but only a single loosely foliose species was sent and not a single fruticose one. Moreover, the loosely foliose lichen sent is especially adapted structurally, as will be noted below. Numbers 3, 5, 6, 7, 28, 30 and 31 were found on the ground and number 24 was collected on the base of a tree trunk in a moist place. These numbers may be omitted from the considerations to follow immediately.

Comparisons with Lichen Formations of Other Regions

The other twenty-five lichens of the list were found on rocks and bear a striking resemblance to those of a "*Lecanora* formation of exposed granite."* The lichens of this formation of exposed granite in Minnesota, and those of several other similar formations studied by the writer in the same state, show barely a larger proportion of foliose species than do the lichens of the rocks at Tumamoc Hill. Not only is there this general structural likeness; but when we take into account the difference in latitude and in moisture conditions, it is remarkable that the genera of the list for Tumamoc Hill are largely represented in the formations of the exposed rocks in Minnesota, while there is also a very considerable likeness in the species. Coville and MacDougal give 11.74 inches as the average annual precipitation of moisture at Tucson, during fifteen years of observation;† while the writer found the record for Granite Falls, Minnesota, where the Minnesota lichen formation used in the comparison above occurs, to be 21.83 inches.‡ This difference is doubtless the main one of the factors which give the Arizona region a lichen flora as a whole very different from that of the Minnesota area, but which are not sufficient to produce striking differences between the lichen floras of rocks in the former region and those of the exposed rocks in the latter place. H. Zukal says: "Auch zeigen die an der Südseite an nackten Felsen wachsenden Flechten und

* Fink, Bruce. Contributions to a Knowledge of the Lichens of Minnesota.—V. Lichens of the Minnesota Valley and Southwestern Minnesota. Minn. Bot. Stud. 2: 286–288. D 1899.

† Coville, F. V., and MacDougal, D. T. Desert Botanical Laboratory of the Carnegie Institution. Pub. Carnegie Institution of Washington 26. N 1903.

‡ Fink, Bruce. Op. c. 279.

jene heisser, regenarmer Gegenden und Wüsten den gemeinsamen Charakter der ausserordentlich verdickten Aussenrinde."§ The studies of the present writer in agreement with those of Zukal show that lichen formations of horizontally exposed rocks in regions of average rainfall, as well as those of perpendicular or inclined, southward-facing rocks, may show the same structure as the lichens of the desert rocks.

In connection with the observations of Zukal and related to other statements above and to problems to be considered below, statements of the writer in a paper recently published are of special interest. In the study of the lichen formations of sandstone ripraps,|| it was found that the northward-sloping riprap supported a lichen formation containing quite a proportion of fruticose and foliose species, while the formation of a southward-facing riprap a few feet away was composed almost exclusively of closely crustose and strongly corticate species. The latter formation, like the lichen aggregations of the rocks in the vicinity of the Carnegie Desert Laboratory, shows *Acarospora* commonly present, while the members of this genus were extremely rare on the northward-facing riprap. This northward-facing riprap supported an abundance of *Biatora myriocarpoides*. which was replaced on the southward-facing riprap by *Buellia myriocarpa,* a lichen whose structure protects it better against the drier habitat through the greater tendency toward disappearance of thallus and the better development of such structures as exciple, hypothecium and paraphyses. It is significant that *Biatora,* with its poorly developed exciples, hypothecia and paraphyses, is entirely wanting in the lichens sent from the area about the Desert Laboratory.

GENERAL CONSIDERATION OF STRUCTURE

It is well known that the more a thallus is branched or lobed, the more young, tender, growing points are exposed and the greater the amount of transpiration of moisture, other things

§ Zukal, H. Morphologische und biologische Untersuchungen über die Flechten. Sitzungsbericht. kaiserl. Akad. Wien. 14: 1308. O 1895.

|| Fink, Bruce. A Lichen Society of a Sandstone Riprap. Bot. Gaz. 38: 269–279. O 1904.

being equal. One may look through the whole list of twenty-five lichens of the rocks without finding more than four species with conspicuously lobed thalli. These four are *Placodium elegans, Placodium murorum, Lecanora muralis* and *Parmelia conspersa;* and these plants, when compared with lichens of the same species from more moist climates, show, as a whole, a perceptible shortening of the lobes of the thalli. Many lichens having the fruticose habit, as certain species of *Evernia,* can scarcely maintain themselves in open places, where subjected to strong gales, but seek protected habitats, as in dense forests, where they will not be torn from their substrata. Also, these fruticose species are usually conspicuously branched and present much surface and many tender, growing areas to the drying effects of winds and dry atmosphere. It is, therefore, not quite certain after all, until further investigation can be made, whether the restriction of lichens about the Desert Laboratory to closely adnate and poorly lobed or branched forms is wholly due to demand for decrease of surface in contact with a drying environment, or whether it is in part a mechanical response against destruction by being torn from their substrata by desert gales.

In general, the twenty-five lichens collected on the rocks of Tumamoc Hill are protected above by some sort of mechanical device, usually a definite pseudoparenchymatous cortex (and enclosed, dead algal cells), which protects the living algal cells and the fungal hyphae of the medullary layer against the drying effects of high winds and the direct rays of sunlight. Zukal has observed that the cortex is thicker in certain lichens growing in places where exposed more than usual to intense light and dry conditions than in the same species in less exposed positions.* One of the most helpful studies in connection with the present problem would be the comparison of some of the species with lichens of the same species from regions having average conditions of light, moisture, temperature, wind, etc., with respect to development of cortex. This, with a more exhaustive study of the functions of coloring matter in the cortex, would help to determine whether the development of cortex in lichens is, as Zukal thinks, mainly a light relation.†

* Zukal, H. l. c.

† Zukal, H. Op. c. 209. Mr 1896.

PROTECTIVE COLORATION

A remarkable thing about these rock-inhabiting lichens from Tumamoc Hill is the more or less evident development of black lines or spots on the upper surface of every species having a light-colored thallus. These lichens or spots are so numerous on older portions of some of the thalli as to darken, more or less, the otherwise light-colored surface. The lines are most conspicuously developed on some of the thalli of *Acarospora xanthophana* and *Parmelia conspersa,* and it was at first thought that they represented parasitic fungi, but sectioning showed that they do not. Zukal, in his excellent discussion of the protective significance of colors in lichens, speaks of such lines of black as occurring on younger or injured portions of thalli to protect the algal cells from the intense rays of sunlight in hot regions;* but the writer found the lines and spots better developed over older portions of thalli and noted that they were frequently developed in connection with cracks in the thalli; nor were the algal cells any more numerous, so far as could be determined, under these black areas than elsewhere in the same thalli. *Parmelia conspersa, Acarospora xanthophana* and *Lecanora muralis* all showed more or less of black margins, which doubtless protect the younger and more tender algal cells of these margins where the cortex is still thin. It was thought that in some of the areolate forms as *Buellia lepidastra* and *Acarospora xanthophana,* in which the thallus is compound, each areole really representing an independent development, the black lines might have been developed at first along the margins and become dorsal by subsequent growth of the areole; but, were this the case, the lines would be as numerous on younger as on older portions of thalli. Besides the species mentioned above, these lines and spots were readily noted in *Acarospora xanthophana dealbata, Acarospora cineracea, Lecanora cinerea* and *Lecanora calcarea contorta.* In section, under the microscope, the upper surface of older portions of some thalli showed the coloring matter often quite generally distributed; whereas under the hand lens it was only apparent where best developed as the black lines or spots, the protective coloration

* Zukal, H. Op. c. 218–221. Mr 1896.

apparently developing gradually from these centers with continued exposure and thus being more abundant in older portions of the thalli.

The isidioid branches were unusually well developed in *Parmelia conspersa* from the desert; and while these branches, of course younger than the horizontal thalli on which they developed, showed only slight and occasional development of the dark lines, they usually showed a brownish coloration at their exposed and tender, growing tips, after the manner of coloration of the tips of branches in many fruticose thalli, which is doubtless protective. *Placodium elegans* showed more or less of the development of darker areas in lighter thalli of the species; but it was not noted in any other thalli of general dark color, these thalli having sufficient coloration of the general surface for protection against intense rays of light in the desert. Nor was it noted that the thalli of any of the twenty-five species were otherwise more deeply colored than lichens of the same species from other regions, except through the development of the black areas and spots, which we must conclude are a protective device.

A very instructive study would be the observation of the relation of development of the black areas to the position of the particular plant on the rocks with reference to the sun's rays. Another problem of interest would be the study of the relation of development of coloration at the tips of the branchlets in *Parmelia conspersa* to the orientation of these branchlets with reference to the sun's rays.

SERIATIM CONSIDERATION OF STRUCTURE

We may now consider *seriatim* the structure of the thalli in the genera most frequently seen in the collections sent for study. *Endocarpiscum* is pseudoparenchymatous throughout, and the algal cells within are thus well protected against too intense light or too much transpiration of moisture, or both. *Acarospora* is also cellular throughout, so that the algal cells are unusually well protected for such small thalli. Like most other lichens whose thalli contain blue-green algal cells, *Endocarpiscum* seems to be confined to the most moist situations in the area, in spite of its special protective devices. Species of *Acarospora,* on the other hand, form a large proportion of the list of twenty-five lichens of the rocks and are more often seen on rocks closely examined than those of any other genus. Perhaps *Acarospora xanthophana* is the most common lichen in the area studied, though the less conspicuously colored *Acarospora Carnegiei* may prove more common on close examination in the region. *Lecanora* has either an upper cellular cortex or a pseudocortex of entangled hyphae, and *Placodium* shows a similar structure. The one *Parmelia* is a very closely adnate species, which the writer has observed to possess a stronger cortex than the closely related *Parmelia caperata,* which usually grows in less xerophytic conditions. *Buellia* shows the special responses to need of protection in the well-developed exciples, hypothecia and paraphyses, which make its existence possible in the dry environment, while *Biatora,* closely related but less favored in these three respects, is entirely absent or so rare as to be entirely overlooked in collecting. *Buellia* has no cellular cortex above, and the algal cells and the surrounding fungal hyphae are protected above only by a thin pseudocortex of entangled hyphae. *Dermatocarpon* is well protected by strong cortices; and *Dermatocarpon miniatum,* the only species not closely adnate, is attached to the rocks by a very strong umbilicus, while the lower cortex is so strongly developed that no ordinary wind can tear the plants from the rocks. This plant is also able to maintain itself more effectively because tough and elastic like rubber when wet, so that, though pliable before the wind in this condition, it is scarcely more likely to be torn loose when wet than when dry. *Pyrenopsis, Endocarpon,* and the two species of *Verrucaria* were rarely seen in the collections and need not be considered important floral elements.

The Stations

The lichens sent for study were collected from seven stations. Station I is the bottom of the gulch a short distance west of the Desert Laboratory, altitude 762 m. The gulch runs northwest, and the lichens of the rocks were collected from rocks facing northward on the west side of the gulch. The lichens of the rocks of the gulch are nearly all on the west side or near the bottom. This peculiar distribution is doubtless largely due to the fact that the rock faces of the east side of the gulch receive the direct rays of the afternoon sun. The lichens sent from the rocks of this station are numbers 8, 10, 12, 13, 15, 16, 17, 19, 20, 22, 23, 26, 27, 32 and 33 of the list of species given above. The lichens found on the soil of the bottom of the gulch are numbers 6, 7 and 31. The rocks forming the walls of the gulch are basaltic.

Station II is a mass of basaltic boulders, forming a cliff facing southward on the south side of Tumamoc Hill, altitude 792 m. The collection was made from all sides of the boulders; and Mr. Blumer reported the south faces of the boulders to be very poor in lichen species and individuals, while the lichen flora is best developed and most highly colored on the north faces of the boulders. The lichens determined from this station are numbers 1, 2, 8, 10, 11, 12, 13, 16, 17, 19, 20, 21, 23, 26, 27 and 32. The similarity between the lichen species of the basaltic rocks of the first two stations will be apparent enough upon noting the similarity in numbering, and especially when one takes into account the genera represented by these numbers as well as the species. Mr. Blumer's notes regarding station II state that a number of moisture-requiring seed-plants, such as *Celtis pallida, Abutilon incanum, Encelia farinosa* and a *Eupatorium* grow about the rocks; and doubtless there are moist places on the rocks where numbers 1 and 2 grow. At least, the writer has found members of the genus *Endocarpiscum* growing in moist places elsewhere. The structural responses of the other lichens found in the first two sections were sufficiently considered in the general and in the *seriatim* statements of adaptations and need not be repeated.

Station III is a very steep slope facing directly south on the south side of Tumamoc Hill, altitude 823 m. The lichen habitat consists of loose blocks of tuff and basalt, especially the former, which have worked down from a quarry above. The habitat is a very dry one, and nothing exists on the ash-dry soil except a few bushes of *Larrea tridentata.* The lichens determined from this station are numbers 8, 9, 10, 11, 12, 13 and 16. The meagerness of lichen species here is very apparent, but it is not certain whether this meagerness is due to the presence of the tuff or to the southern exposure. Mr. Blumer stated in a letter that the lichens seem to grow better on the basalt, but only one of the stations reported is composed entirely of tuff, so the question of relative suitableness of the two kinds of rocks for lichen substrata cannot be certainly solved from data at hand. Mr. Spalding and Mr. Blumer both stated in letters that lichens are very scarce on southward-facing rocks, the latter gentleman writing: "Their place of best development is on the northerly faces of basaltic rocks, where they are often beautifully conspicuous. On sunny aspects of rock faces they must be looked for to be found." However, the most remarkable thing about the short list of seven lichens found in this station is that five of them belong to the genus *Acarospora,* and that every species and subspecies of the genus known to occur on Tumamoc Hill is found in this one station. The writer must again refer to his work in Minnesota,* where he has found the genus represented in every one of the six lichen formations of exposed horizontal rocks studied, whether on granite, quartzite or pipestone, and in all but one by the species *Acarospora xanthophana.* Also, he must recur to his statement, in the paper on "A Lichen Society of a Sandstone Riprap,"† regarding the frequent occurrence of *Acarospora* on the southward-facing riprap and its very rare occurrence on the northward-facing riprap a few feet away. These data, with those of station III, establish beyond doubt that *species of Acarospora, with their strong protective cortices and their cellular structure throughout are the most characteristic xerophytes of all our American lichens thus far studied from the ecologic point of view.* They occur in xerophytic associations as a small proportion of the plants of lichen formations in exposed environments in regions for the most part mesophytic, and are found at station III making a very large proportion of a lichen aggregation on the southward-facing, dry and often hot rocks of a desert region.

Station IV is in the same locality as station II, but differs in that it is an outcrop of tuff facing eastward at the bottom of the exposure. The plants determined from this station are numbers

* Fink, Bruce. Op. c. and other papers of the same series.

† Fink, Bruce. Op. c. 278.

1 and 2 of the list. The eastward-facing tuff at the bottom of the exposure is doubtless often moist, so that *Endocarpiscum* finds a favorable habitat. It is not a little remarkable that the tuff, even at the base of the exposure, gave only two lichens; and, while it can hardly be possible that the absence of other lichens from the formation is more than a singular accident in distribution, if indeed the collecting was in this instance carefully done, the data at hand tend strongly to prove that tuff is a very poor substratum for lichens.

Station V is a northward-facing basalt cliff on the north side of Tumamoc Hill, just west of its summit, altitude 914 m. Mr. Blumer thinks that this is perhaps as moist and cool a place as can be found about the Desert Laboratory, but he writes that even here lichens are absent from certain rock crevices and faces that are perennially dry, and are for the most part limited to such surfaces as are frequently wet or moist. The lichens found in this station are numbers 6, 7, 8, 10, 13, 15, 16, 19, 23, 26, 27, 30 and 33. The general similarity of this list of lichens and that of station I is apparent enough from the numbers, and it need only be stated that the gelatinous lichens which commonly grow in moist and shaded habitats are represented on the rocks here by numbers 6 and 7. This comparatively moist and cool station is the only one at which these species were found upon the rocks. The failure to get *Endocarpiscum* from this station is doubtless due to an oversight in the collecting.

Station VI is at the bottom of the gulch west of the Desert Laboratory, on the north slope, about an old tuff quarry, altitude 747 m. The rocks are tuff, with a few basaltic boulders, and the station is drier than station V. The lichens found in this station are numbers 3, 4, 8, 9, 10, 11, 13, 15, 16, 17, 18, 19, 23, 26 and 33. The general similarity of this lichen assemblage to that in station I is readily seen. The present station shows a larger number of species of *Acarospora* than did station I, and the individuals of this genus predominate more plainly in the present station, if one may judge by the material sent. The tuff is doubtless a drier rock than the basalt, not holding water so well, and it would seem that is supports a fairly well developed lichen flora on the northward-facing exposures, but not on the southward-facing. However, station VI contains basalt as well as tuff, and this conclusion can not be regarded as secure until several stations composed entirely of tuff are examined. The prevalence of tuff in the present station doubtless accounts for the drier conditions which have given species of *Acarospora* in greater numbers.

Station VII is the north face of a basalt block near the Desert Laboratory. The lichens determined from this station are very similar to those from stations I and VI, and a consideration of them would add nothing of value.

LICHENS OF SOIL AND TREES

At all of the stations an effort was made to find lichens on the soil. At stations II, III, IV, VI and VII nothing was found on the earth, while from stations I and V were found numbers 5, 6, 7, 28, 30 and 31. Mr. Blumer stated that the lichens collected at station V were found on wet soil, nothing appearing to the eye on dry soil. Inconspicuous lichens are much more easily visible when moist, and this fact may account for the difference in appearance, but Mr. B. E. Livingston has found that the soil becomes air-dry for a considerable depth during dry seasons,* and it is more probable that the lichens of the soil, whose short rhizoids penetrate but a small portion of the distance down to soil moisture in drier situations, are for the most part confined to shaded places where the moisture is retained longer and where it is doubtless drawn upward along the faces and crevices of the rocks extending into the soil, so that the lichens can get more moisture from below than they could get by evaporation through the air-dry layer of soil above the caliche in drier places. A thorough study of the earth-inhabiting lichens of the region should be made, however few may be the number of species found, for the sake of the light that would be thrown upon general ecologic problems.

The lichen flora of the woody plants of the area must be very limited, for repeated requests for such material brought nothing but a few sterile and poorly developed specimens of a *Physcia* and a *Placodium*. These were collected on *Parkinsonia microphylla,* very close to the ground, among rocks on a north slope.

* Livingston, B. E. The Relation of Desert Plants to Soil Moisture and to Evaporation. Pub. Carnegie Institution of Washington, 8. Au 1906.

RELATIONS TO MOISTURE AND AIR MOVEMENTS

It still remains to discuss several factors which influence lichen distribution in the area under consideration and at the same time to state several further problems that may well receive attention at some future time. Regarding the atmospheric conditions likely to influence lichen distribution, relative humidity and air movements are doubtless the most important factors. The relative humidity is known to be as low as eight per cent. of saturation about the Desert Laboratory, at times of special dryness in summer, and it varies from this to a high relative humidity during the rainy seasons. The ordinary winds blow from the east in the morning, later from the south, and by the middle of the afternoon from the west, while the gales may come from any direction. The drying winds from the east, south and west, day after day, doubtless interfere somewhat with the development of lichens on these three sides of outcrops of rocks, accentuating the effect of direct sunlight, thus leaving the northward-facing ledges by far the best habitats for lichens.

Mr. V. M. Spalding has shown certain desert seed-plants to absorb more or less water through their leaves and young shoots, some of them as much as nineteen per cent. of their weight,* and has also found that certain species of desert seed-plants absorb a very small amount of water vapor from a nearly saturated atmosphere, through their leaves and twigs.† He thinks that this absorption of water and water vapor through the leaves and twigs may be of some slight advantage.

H. Jumelle has experimented with lichens in somewhat similar fashion, in order to ascertain the amount of dryness of lichens in their habitats.‡ He collected several widely different species from trees and rocks, weighed them, placed them in a desiccator and weighed them again after drying. Jumelle's first experiments were performed upon lichens taken at a time when quite dry and supposed to be in a latent condition, and he found the

* Spalding, V. M. Biological Relations of Desert Shrubs.—II. Absorption of Water by Leaves. Bot. Gaz. 41: 262–282. Ap 1906.

† Spalding, V. M. Absorption of Atmospheric Moisture by Desert Shrubs. Bull. Torr. Club 33: 367–375. Jl 1906.

‡ Jumelle, H. Recherches Physiologiques sur les Lichens. Rev. Gen. Bot. 4: 115. Mr 1892.

relation of fresh weight to dry weight to vary from 1.14 to 1 in *Parmelia acetabulum* to 1.21 to 1 in *Teloschistes parietinus.* He thinks that respiration and assimilation in lichens are reduced to almost *nil* in dry times. He found that *Cladonia rangiferina* and some other higher lichens can endure the dry condition for three months, and, upon the return of moist conditions, the life energies gradually return to their normal condition. Jumelle also experimented with lichens collected at times when they should be near their maximum regarding water content in their natural habitats, and got no very striking increase in the amount of water present in their thalli, the figures for *Parmelia acetabulum* at two different times being 2.07 to 1 and 1.38 to 1. He also dipped lichens into water several times, wiped them carefully and weighed them at once and also after drying. He found that the relation between the saturated weight and the dry weight is for *Parmelia acetabulum* 3.36 to 1, a proportion above the average for nineteen lichens experimented upon by him.

Jumelle has also experimented in similar fashion with seed-plants and has found that the proportion between fresh and dry weight varies from 10 to 1 up to 20 to 1. This shows that lichens, compared with seed-plants, contain very little water at any time, though the former are much more able to absorb water or water vapor in the proportions needed than are the latter, according to the experiments of Spalding. It must be further stated that Jumelle found a *Collema* dipped in water to show the surprising proportion of 35 to 1. He therefore concludes that the gelatinous lichens have a very high absorbing power. But these aside, lichens need very little water and are able to obtain all that is needed through the general surface, instead of through specialized organs as roots; the power of lichens to absorb water and water vapor through the general surface being high as compared with the results obtained by Spalding for the leaves and twigs of certain desert seed-plants. All considered, it may be assumed until otherwise proven, that lichens absorb at least a large proportion of the moisture needed, directly from water vapor of the atmosphere and from water falling upon them. However, so far as the writer can ascertain, the statements made by Jumelle do not rest upon experiments made upon any desert lichens, and similar experiments with some of the lichens about the Desert Laboratory would certainly give some very instructive results.

Zukal, in summing up regarding the hygroscopicity of lichens, says: "Die Hygroskopicität ist für die Flechten eine höchst wichtige Eigenschaft, und nicht wenigen Arten ermöglicht sie geradezu die Existenz. Dies gilt besonders für die Bewohner jener Gegenden, wo es nur wenige Tage im Jahre regnet, wie dies z. B. in manschen Landschaften Chiles, Australiens und Nordafrikas der Fall ist."* It is doubtless true that hygroscopicity is of very considerable use to the crustose lichens of the deserts; though the most hygroscopic lichens are not the crustose ones, which seem to constitute almost the whole lichen flora of the desert area under consideration, nor yet the closely foliose ones that form a very small proportion of the lichen flora of Tumamoc Hill, but the loosely foliose and the fruticose species, especially those covered with hairs, cilia and free rhizoids. Experiments similar to those of Spalding and Jumelle, performed upon the crustose lichens of the desert in the driest condition in nature and giving the relation between fresh and dry weight, would give data regarding the amount of moisture retained in lichen thalli during the driest times in the desert. Accompanying this should go observations regarding the length of time that these lichens may be kept dry and then resume active respiration and assimilation on the return of favorable conditions.

Lichens can get water from the surface of the ground or rocks for a short time during and after each rain or wet season; but they have no special adaptation for storing water like cacti, nor have they organs extending any considerable distance into the soil or into rock crevices by which, like many seed-plants, they could extract soil moisture from any considerable depth. The retreat of the evaporating surface into the soil therefore leaves any lichens growing upon exposed soil entirely in an air-dry environment; consequently, the ability of these lichens, if lichens exist in such habitat, to absorb both water and water vapor from the atmosphere would be of special use to them in withstanding the effects of prolonged drought. This brings us to the ques-

* Zukal, H. Op. c. 1346. O 1895.

tion of how much moisture the lichens of the rocks in the desert may be able to obtain from upward passage through the rocks. It is well known that rocks are more or less porous and that the pores are larger toward the surface, porosity ranging from less than one per cent. to thirty per cent. or more. C. R. Van Hise states that water may rise 166 meters by capillarity, that, after it has ascended as high as it can by capillarity, it will still, through molecular attraction, creep along the walls of the pores "from areas of greater to areas of less humidity," and that there is no limit to such movement.*

No reliable data are at hand regarding the porosity of the tuffs and basalts of Tumamoc Hill and the amount of water that reaches the surface through them. The basalt is more dense and less porous than the tuff, and the latter may, like the soil, give off moisture so rapidly as to become too dry to support lichens very successfully through periods of prolonged drought. The less porous basalt doubtless gives off water vapor coming up from great depths very slowly, but perhaps in sufficient quantity to keep the lichens growing on these rocks alive in the driest times known in the desert; at least on surfaces often wet during the rainy season, and especially on northward-facing exposures where the effect of prolonged drought is felt least. Mr. Spalding stated, in answer to inquiry, that the lichens seem to be quite as numerous on large boulders as on the rock exposures *in situ*. The boulders do not extend to great depth; but if they extend below the lower limit of evaporating surface in the soil in driest times, the problem of distribution of lichens on them might not differ materially from that of their distribution on other rocks. This question of water supply for the lichens from the rocks below them is well worth investigation at the Desert Laboratory. It is certain that the supply obtained in this way is not alone sufficient to sustain lichens, for observation proves that these plants do not grow on desert rocks perennially dry. But the moisture thus obtained may be sufficient to keep the lichens alive during periods of extreme dryness, in situations where they may obtain moisture otherwise during rains and wet seasons.

* Van Hise, C. R. Treatise on Metamorphism. No. 753. Geol. Surv. Mon. 47: 151. 1904. (House Documents, vol. 83.)

CONCLUSION

This brief study of the ecologic relations of some desert lichens should be of special interest, since it is the first one to appear. The workers in ecology have very largely confined their attention to seed-plants, but there is certainly a problem of great interest in the study of ecologic distribution of lichens in the desert as well as elsewhere. The writer has been at the disadvantage of not being able to see the field, and had it not been for the painstaking manner in which Mr. Spalding answered all inquiries and the careful collecting and note-taking of Mr. Blumer, the results herein presented would not have been possible. The writer realizes very fully that there are other problems concerning the distribution of lichens in the area herein considered, doubtless of as great importance as the ones discussed or suggested herein, that would present themselves during the progress of a study of the problem in the field.

While the writer was studying the ecologic problems, a number of the lichens collected were sent by him to Mr. Theodor Hedlund and to Mr. A. Zahlbruckner in Europe for aid in the taxonomic study. Thanks are due to both of these gentlemen for their aid in the work. Six new species and one new subspecies result from the work of Zahlbruckner (see Bull. Torr. Club **35**: 297–300. Je 1908).

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